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REVIEW ARTICLE

The Prevention and Control of Bacterial Foodborne Hazards in Meats and Meat Products-An Overview

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Abstract

Bacterial foodborne hazards are implicated in foodborne disease outbreaks and human infections. Developed countries with better monitoring systems have reported cases of foodborne infections resulting in human illnesses, hospitalizations and even death. Bacteria hazards commonly involved in the cause of human foodborne infections include *Salmonella* species, *Campylobacter* species, *Listeria monocytogenes*, *Escherichia coli*, *Staphylococcus aureus*, and *Clostridium perfringens*. Consumption of foods of animal or plant origin and their products contaminated with these hazards has been responsible for human foodborne infections. Changes in human lifestyles and climatic conditions have affected the pattern and outbreak of bacterial foodborne infections. Ignorance on the part of some humans and the ability of bacteria hazards to change and adapt to varying unfavorable environmental conditions have also complicated effective control and prevention methods. Nonethessless, several precautions have been set up and researches have been conducted to come out with measures to prevent or control bacterial foodborne hazards. It is essential to reduce or prevent the incidence of foodborne illnesses which can lead to several complications and death under severe conditions. This paper provides an overview of the measures and methods that can be adapted for the control and prevention of bacterial foodborne hazards in meat and meat products.

Key words: Bacterial foodborne hazards, Foodborne infections, Prevention and control.

1. Introduction

Bacterial foodborne hazards (or bacterial foodborne pathogens) are any bacteria in food with the potential to cause an adverse health effect (ICMSF, 2002). Foodborne hazards also include biological agents (e.g. fungi, parasites, some viruses), chemicals (e.g. pesticides, fertilizers) or physical hazards (e.g. bones, stones, metals, bolt) (Jay, 2000). Of all these foodborne hazards the likelihood of becoming seriously ill by bacterial foodborne hazards is far greater than that of biological, chemical, or physical hazards, and by nutritional imbalances and natural toxicants (Adam and Moss, 2008). Bacteria hazards associated with meats and meat products and responsible for human infections are usually single cell organisms, microscopic in nature, multiply by binary fission, and grow over a wide range of temperature, pH and environmental conditions (Jay, 2000; Adam and Moss, 2008). They include *Salmonella* species, *Shigella* species, *Campylobacter* species, *Escherichia coli*, *Bacillus cereus*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Clostridium perfringens* and *Clostridium botulinum* (Abley *et al*., 2012; Mezali and Hamdi, 2012; Rubal *et al*., 2012; Desai *et al*., 2015; Ajay Kumar *et al*., 2014; Chaudhary *et al*., 2014). The common symptoms of foodborne infections are nausea, vomiting, abdominal cramps and bloody or non-bloody diarrhea which are usually self limiting. Under severe cases foodborne infections can lead to complications such as bacteremia, Guillain-Barré syndrome, Reiter's arthritis, hemorrhagic colitis, haemolytic-uremic syndrome, haemolytic anaemia, and death (Jay, 2000; Adam and Moss, 2008). The consumption of meats and meat products contaminated with bacterial foodborne hazards can lead to foodborne infections, an issue of greater public health concern. Furthermore, meats and meat products contaminated with bacterial hazards would have short shelf life or spoil early and can results in huge financial losses to the meat industry (Adzitey, 2011; Adzitey *et al*., 2011; Adzitey and Huda, 2012).

The growth of bacterial foodborne hazards on or in meats and meat products is supported by favorable conditions such as suitable nutrients, moisture, oxygen, pH, temperature, and relative humidity (Jay, 2000; Adam and Moss, 2008). Bacterial foodborne hazards have or can also develop certain characteristics that favour their multiplication and growth under harsh and unfavorable conditions. Such characteristics include the production of antimicrobial agents, having protective biological structures, mutation and formation of biofilms which can enable them to resist prevention and control measures/methods. Moreover, meats and meat products are rich in nutrients especially proteins and moisture which comfortably support the multiplication and growth of bacterial foodborne hazards. An understanding of the factors that favour the growth of bacterial foodborne hazards would play a significant role in the control and prevention of contamination and foodborne infection (Mane *et al.*, 2014). The concept of preventing and controlling bacterial foodborne pathogens is perhaps of paramount importance than curing or treating humans made ill or sick by foodborne pathogens. The increasing resistances of bacterial foodborne hazards to antibiotics also make it difficult to treat people infected with foodborne infection, thus prevention and control measures are more essential (Dhanze and Mane, 2012). The prevention and control of foodborne hazards should be practiced at every stage or point in the food chain, thus from farm-to- fork or farm-to-table.

This paper provides an overview of the measures and methods to be adapted to prevent and to control the spread of bacterial foodborne hazards and consequently foodborne infections. It also provides brief information about the prevalence or presence of bacterial foodborne hazards, foodborne outbreaks associated with the consumption of meats and meat products, and the challenges and future trends in the prevention and control of bacterial foodborne hazards.

2. Prevalence of Bacterial Foodborne Hazards in Meats and Meat Products

Countless number of works on the prevalence of bacterial foodborne hazards isolated from meats and meat products have been reported globally. Among them are studies by Adzitey *et al*. (2012a); Abley *et al*. (2012); Mezali and Hamdi (2012); and Rubal *et al.* (2012). Rubal *et al*. (2012) reported a prevalent rate of 22.86% for *Salmonella*, 42.86% for *Escherichia coli* and 82.86% for *Staphylococcus* in chicken breast and 25.71% for *Salmonella*, 42.86% for *Escherichia coli* and 85.71% for *Staphylococcus* in chicken thigh in a poultry processing facility in Bangolore, India. Adzitey *et al.* (2012a) found that 10% of duck caresses collected from Penang, Malaysia were contaminated with *Salmonella* species. In Algiers, Algeria, Mezali and Hamdi (2012) sampled 144 raw red meat and meat products, 128 raw poultry meat and poultry products, and 42 processed meat products from various retail outlets and found that 61 (19.43%) tested positive for *Salmonella*; 23.6% and 17.97% of the red meat and poultry, respectively were positive for *Salmonella*. Abley *et al.* (2012) indicated that the proportion (%) of *Campylobacter* positive samples were 55 and 12 for beef carcasses and meat samples, respectively.

Furthermore, the presence of *Escherichia coli*, *Campylobacter* species, *Listeria monocytogenes, Staphylococcus aureus, Clostridium perfringens, Yersinia enterocolitica Bacillus cereus*, and other bacterial foodborne hazards in poultry, turkey, ducks, chevon, mutton, beef, pork and their products have been reported (Bostan *et al*., 2009; Adzitey *et al.*, 2010; Eglezos *et al*., 2010; Abley *et al*., 2011; Adzitey *et al*., 2011; Atwa and Abou EI-Roos, 2011; Waters *et al.*, 2011; Adzitey *et al.*, 2012b, Adzitey *et al*., 2012c; Adzitey *et al.*, 2012d; EFSA; 2012; Ajay Kumar *et al.*, 2014). The prevalence of bacterial foodborne pathogens in meat and meat products would not remain constant over time within a geographical area. It will continue to vary between and within regions, the number of samples examined, the period of sampling, the method of isolation, the type of samples examined and the type of foodborne hazards to be isolated.

3. Incidence of Bacterial Foodborne Outbreaks Associated with Meats and Meat Products

Undoubtedly many bacterial foodborne outbreaks and infections go unreported. This is particularly so in less developed and developing countries not having or lacking proper monitoring and reporting systems for investigating foodborne outbreaks and infections. In developed countries, where the reporting and monitoring systems are better, it is also suspected that the incidence of foodborne outbreaks and infections are under reported due to numerous challenges in collecting and analyzing epidemiological data. For instance, from the time a person is diagnosed of a particular foodborne infection, that person might have consumed a variety of foods making it difficult to trace the actual source of infection. Under small scale production, the food that made the person ill may not be available for testing. CDC (2012) reported an outbreak of *Salmonella*

Enteritidis linked to ground beef which resulted in the hospitalization of 12 people after 46 persons were infected. An outbreak of *Salmonella* Typhimurium from the consumption of contaminated ground beef made 20 persons sick (CDC, 2011a). A total of 190 illnesses due to the outbreak of *Salmonella* Heidelberg were linked to kosher broiled chicken livers (CDC, 2011b). *Salmonella* Heidelberg was also responsible for foodborne outbreaks involving 136 infected persons who had consumed contaminated ground turkey (CDC, 2011c). In 2009, a multistate outbreak of *Escherichia coli* O157:H7 infections were associated with beef and poultry (CDC, 2010).

Bacterial foodborne outbreaks associated with meats and meat products in the EU are provided in Table 1. Outbreaks of *Campylobacter* infection from the consumption of broiler meat and products was the highest followed by outbreak of *Clostridium* and *Staphylococcus* infections from mixed or unspecified meat and products. The least was outbreak of *Salmonella* infection from the consumption of mixed or unspecified meat and products.

Reliable reported foodborne outbreaks and human infections in most developing countries are very scare if not available.

4. Prevention of Bacterial Foodborne Hazards in Meats and Meat Products

The occurrence of bacterial foodborne hazards and the outbreak of bacterial foodborne infections can be reduced by adapting preventive measures. Preventive measures will reduce or prevent colonization and cross contamination, and consequently reduce the spread of bacterial foodborne hazards during processing of meats and meat products (Jay, 2000; Adams and Moss, 2008; Bostan *et al*., 2009). The prevention of bacterial foodborne hazards in meats and meat products requires the adaption of certain measures including good agricultural practices in the husbandry of animals, good manufacturing (processing) practices during meat processing, the adherence to HACCP principles in the slaughtering and processing of meats and meat products, and increasing education for everyone/consumers in the proper ways of handling meats and meat products to prevent contamination and infections (Jay, 2000; Warriss, 2000; Adams and Moss, 2008; Adzitey and Huda, 2011).

4.1 Good Agricultural Practices (GMP's)

The first key to preventing bacterial foodborne hazards in meats and meat products is to practise good agricultural practices in the husbandry of animals. The breeding of animals, rearing, and transporting animals to slaughter houses/abattoirs should be done right and under hygienic conditions (Adzitey, 2011; Warriss, 2000). Animals should be provided with proper and clean housing, adequate and balanced feed, sufficient portable drinking water, and well planned recommended health care. Wastes should be disposed of regularly and should not be allowed to come in contact with animal feed and water. Vaccination and antibiotic administration schedule using recommended dose by the manufacturer should be strictly adhered to. Practice good animal welfare throughout the production process (Adzitey, 2011; Warriss, 2000). Harvest animals at the right age and load animals for the abattoir with care. Transport animals over short distances as possible to slaughter points, provide sufficient rest for long distances and do not overcrowd them in the transporting vehicle. In general stress should be kept to minimum to reduce the shedding of bacterial foodborne hazards during transportation (Adzitey, 2011; Warriss, 2000; Chang *et al*., 2012).

4.2 Good Manufacturing Practices (GMP's)

Good manufacturing (processing) practices (GMP's) is another important strategy that can be adapted to prevent the spread of bacterial foodborne hazards. These practices involve following certain minimum sanitary and processing requirements during lairaging, animal killing, dressing and processing into finished products necessary to ensure that meats and meat products are safe and wholesome for consumption (Adzitey, 2011; Anonymous 2012; Chang *et al.*, 2012). As part of GMP's, abattoirs and meat processing factories should keep detail records of activities including conditions of animals before slaughter, sources of the animals, number slaughtered, number of meat products produced, lapses during processing, labeling of products, where finished meats and meat products are sent/ship to. (FDA, 1997a; Anonymous, 2012). All equipment and machines should always be clean, functional and in good condition. They should be sanitized, serviced and maintained regularly (FDA, 1997a; Chang *et al*., 2012). Floors, walls and other places that can harbour bacterial foodborne hazards should be cleaned immediately after operation. Storage facilities including chillers and transporting vehicles should be able to protect meats and meat products from contamination and deterioration. Qualified persons should be employed or allowed to work in abattoirs and meat processing factories. They should be aware of disease control measures and practice standard level of personnel hygiene and cleanliness during processing operations. They should also be given routine training on GMPs, good hygienic practices (GHP's), standard-

Table 1: Strong evidence bacterial foodborne outbreaks caused by pathogens isolated from meat and meat products in the EU, 2010.

Meat and meat product	Percentage bacteria foodborne outbreak (%)				
	Salmonella	*Campylobacter*	*Staphylococcal* toxins	*Clostridium* toxins	*Bacillus* toxins
Broiler meat and products	5.3	63	5.3	6.3	N/A
Bovine meat and products	4.7	N/A	5.3	12.5	3.8
Pig meat and products	5.3	N/A	5.3	6.3	N/A
Mixed or unspecified meat and products	4.1	7.4	15.8	37.5	N/A

Source: EFSA (2012); N/A: Not available

Table 2: Heat resistance/decimal reduction times of selected bacterial foodborne hazards

Bacterial foodborne hazard type	Temperature/Time					
Vegetative	50 °C	60 °C	65 °C	70 °C	75 °C	80 °C
E. coli	4-7 min	-	-	-	-	-
Salmonella spp.	-	-	0.02-0.25 min	1.2 sec	-	-
L. monocytogenes		5-8 min		0.1-0.3 min		
Staph. aureus	-	-	0.2-2 min	-	-	2 sec
Campylobacter spp.	1.1 min	-	-	-	-	-
Enterobacter spp.	-	-	-	-	3 sec	-
Spoilage bacteria	-	-	0.5-3 min	-	-	-
Spores	100 °C	121 °C				
Bacillus spp.	0.1-0.5 min	-	-	-	-	-
Cl. botulinum	50 min	0.1-0.2 min				
Cl. sporogenes	-	0.1-1.5 min	-	-	-	-

FAO (2007)

operation procedures (SOP's) and new technologies available in meat processing, and the prevention and control of bacterial foodborne hazards. Finally, workers in meat processing plants should always wear appropriate clothing's, conduct and behave well at work, and should receive effective supervision to ensure adherence to GMP's, GHP's, SOP's, and HACCP principles (Brown, 2000; Anonymous, 2012; Chang *et al.*, 2012).

4.3 Hazard Analysis Critical Control Point (HACCP) support with references

The application of Hazard Analysis Critical Control Point (HACCP) principles in the husbandry of animals, and especially in the processing of meats and meat products will prevent and control foodborne hazards at the same time. Effective HACCP system will identify, evaluate, and control all hazards with the potential to cause an adverse health effect (Brown 2000; FDA, 1997b; CAC, 2012). In HACCP system, controls and if possible preventions are applied at the Critical Control Point (CCP) step to prevent or eliminate any bacterial foodborne hazard or reduce it to an acceptable level (FDA, 1997b; CAC, 2012). The target of HACCP is rather to eliminate or minimize by prevention during production rather than by inspection of the finished product (FDA, 1997b; CAC, 2012). Thus the emphasis is to prevent hazards at the earliest possible point in the food chain; that is on the farm. Detailed examples of the application of HACCP principles in the control and prevention of bacterial foodborne hazards in meats and meat products, and others can be found at CAC (2012).

4.4 Public Awareness

The last but not the least point under consideration here is to create public awareness and to provide appropriate education for anyone involve directly or indirectly in the handling of meats and meat products. Meat handlers, meat processors, consumers, the public and all stakeholders have to be made aware or educated on what bacterial foodborne hazards are, their effects, how they are spread and contracted, and how to prevent and to control them.

5. Control of Bacterial Foodborne Hazards in Meats and Meat Products

A number of methods are available for controlling bacterial foodborne hazards on or in meats and meat products. These methods either kill, reduce bacteria numbers or prevent them from multiplying and growing. These methods usually manipulate extrinsic and intrinsic factors required by bacterial foodborne hazards to grow to achieve the desired control. These methods include chilling and freezing, thermal treatments, drying and salting, radiation, packaging and many more.

5.1 Thermal Treatments

Thermal treatments involve the application of any sort of heat to control bacterial foodborne hazards. Thermal treatments that can be applied to meats and meat products include scalding, singeing, hot water treatment, steaming and cooking. Thermal treatment will normally kill bacterial foodborne hazards or reduce their numbers, and extend meats and meat products shell life. Thermal treatments can also enhance desire texture, flavor, taste and colour of meats and meat products. Whyte *et al*. (2003) found that hot water immersion of broiler thighs at 80 and 85 ^{o}C for 10 s resulted in a significant reduction of 1.09 and 1.25 cfu/g_{10} in total viable bacteria. Exposure to steam at 90 ^{o}C for 24 s also resulted in significant reductions of 0.75, 0.69 and 1.3 $\log_{10}$ cfu/g for total viable counts, *Enterobactericeace* and *Campylobacter*, respectively (Whyte *et al.*, 2003). Corry *et al*. (2007) showed an overall reduction of 1.66 $\log_{10}$ cfu/cm^2 for *Campylobacter* after hot water immersion treatment at 75 °C for 30 s and a reduction of 1.31 $\log_{10}$ cfu/cm^2 for *Escherichia coli* following hot water immersion treatment at 80 °C for 20 s. Schlisselberg *et al*. (2013) found a mean reduction of 2.8 and 2.5 log cfu/g in total indigenous bacteria after cooking meatballs (inoculated with 8 log cfu/g of various foodborne hazards) with the conventional and controlled radio frequency energy, respectively. They also reported a reduction of 5.5 log cfu/g and undetectable level (*Escherichia coli*), 6.5 and 5.7 log cfu/g (*Salmonella* Typhimurium), undetectable level and 0.4 log cfu/g (*Listeria monocytogenes*) by the conventional and controlled radio frequency energy, respectively. Table 2 summarizes the required heat and time (decimal reduction times) needed to control some bacterial foodborne hazards. Table 2 shows that vegetative bacterial foodborne hazards can be destroyed at temperatures between 50-80 ^{o}C depending on the type. However, they are all destroyed at a temperature of $\geq$ 100 ^{o}C. Nonetheless, bacterial foodborne hazards that produce spores can survive higher temperatures above 80 ^{o}C and thus require temperatures $\geq$ 100 ^{o}C to control them. This suggests that specific heat treatment temperatures and times are to be applied at specific stages of meats and meat products processing to control specific or group of bacterial foodborne hazards.

5.2 Drying/Desiccation and Salting

Drying/desiccation and salting are old systems for preserving meats and meat products to control bacterial foodborne hazards. They function by reducing water activity thus making moisture insufficient for cellular activities of bacterial foodborne hazards. Drying leads to gradually dehydration of meats cut into required sizes and shapes, and exposing the cut pieces to the sun or under control heat. Placing meats or meat products in high concentration of salt will cause water to leave the cells of bacterial foodborne hazards disrupting the normal functions of the cell, stopping growth and finally death of the bacterial hazard. Marindes (mainly of brine solution and other minor ingredients) was used by Birk *et al.* (2010) to obtain a 1.2 $\log_{10}$ reduction in *Campylobacter* on chicken fillets after three days of storage in low pH marindes (pH<3). Table 3 shows the approximate growth limiting conditions for some bacterial foodborne hazards.

Table 3 suggests that, a salt concentration of 5% w/w can reduce the water activity in meats or meat products to 0.97 and at a storage temperature of <4^{o}C and pH <5, the growth of *Bacillus cereus* in meats or meat products can be controlled.

5.3 Radiation

Both ionization (x rays, gamma rays and electron beams with short wave length and high energy) and nonionizing (e.g. ultraviolet with long wavelength and less energy) radiations can cause ionization of water within foodborne bacterial cells on or in meats and meat products resulting in the formation of hydroxyl radicals and thymine dimmers, respectively thus destroying the cell components to bring about the death of bacterial foodborne hazards. Approximately between 10 to 50 kGy of radiation is needed to kill bacterial foodborne hazards (Anonymous, 2012). Jo *et al.* (2004) investigated the efficacy of irradiation to inactivate some bacterial foodborne hazards in raw marinated beef rib and reported D_{10} values of 0.663±0.01, 0.594±0.05, 0.636±0.02, and 0.538±0.01 kGy for *Staphylococcus aureus*, *Bacillus cereus*, *Salmonella* Typhimurium and *Escherichia coli*, respectively. Badr (2004) found that γ irradiation of rabbit meats with 3 kGy reduced the counts of *Staphylococcus aureus*, *Listeria monocytogenes*, *Enterococcus faecalis* and-

Table 3: Approximate growth limiting conditions for some bacterial foodborne hazards

Bacterial Foodborne Hazard	Inhibitory water activity	Equ. Salt Conc. (%w/w)	Mini Growth Temp. (°C)	pH
Bacillus cereus	0.97	5	4, 10*	5.0
C. jejuni	0.98	11	32	4.9
C. perfringens	0.95	7	12	5.0
E. coli (VTEC)	0.95	8	7	4.0
L. monocytogenes	0.92	12	0	4.3
Salmonella spp.	0.93	11	5	3.8
S. aureus	0.86	19	7	4.0
Y. enterocolitica	0.95	7	-2	4.2

*Lund et al. (2000); * = psychrotropic and mesophilic strains; Equ.: Equivalent; Min: Minimum; Conc. Concentration; Temp.: Temperature*

Table 4: D_{10} values of some bacteria foodborne hazards

Bacteria foodborne hazard	Non frozen (kGy)	Frozen (kGy)
Camplobacter jejuni	0.08 – 0.20	0.21 – 0.32
E. Coli O157:H7	0.24 – 0.27	0.31 – 0.44
Staphylococcus aureus	0.26 – 0.60	0.30 – 0.45
Salmonella spp.	0.30 – 0.80	0.40 – 1.30
Listeria monocytogenes	0.27 – 1.00	0.52 – 1.30
**Shigella* spp.	0.22 – 0.40	0.22 – 0.41
**Yersinia enterocolitica*	0.04 – 0.21	0.20 – 0.39

*Anonymous (2012); *Farkas (2005). D_{10} or D-value is the equivalent to radiation dose required to reduce a bacterial population 90%.*

Enterobacteriaceae by more than 3, 3, 1.4 and 4 log units, respectively. At this irradiation dose *Salmonella* was not detected (Badr, 2004). An irradiation dose of 3 kGy extended meat products (chicken chilly, mutton shammi, kababs and pork salami) shelf life by more than 2 weeks at 0-3 ^{o}C and *Staphylococcus* spp. were completely eliminated at a dose of 2 kGy (Kanatt *et al.*, 2005).

Table 4 provides typical D values for some bacterial foodborne hazards. Table 4 shows that the highest radiation dose of 0.30-0.80 kGy is required to kill *Salmonella* spp. on non frozen meats or meat products, while the highest radiation dose of 0.52-1.30 kGy is required to kill *Listeria monocytogenes* in or in frozen meats and meat products.

5.4 Chilling and Freezing

Chilling and freezing are temperature reduction processes used to control the growth of bacterial foodborne hazards on or in meats and meat products. Meats and meat products are normally chilled at temperatures between 0 to 4 ^{o}C, while freezing of meats and meat products is done at a temperature of 18 ^{o}C. Carcasses and meats are chilled immediately after slaughtering and the cold chain maintained throughout the production chain to slowdown the growth of bacterial foodborne hazards and other undesirable physicochemical and biochemical changes in meat. In freezing, water form crystals making it unavailable for the growth of foodborne bacterial pathogens. Thus frozen meats and meat products can be stored over several months because freezing can completely stop the growth of bacterial foodborne hazards. Garden-Robinson (2012) reported a suggested freezing times for various meats and meat products such as bacon (1 month), frankfurters and ham (1-2 months), beef and lamb roasts (6-12 months), pork and veal roasts (4-8 months), beef steak (6-12 months), lamb and veal chops (6-9 months), and pork chop (3-4 months).

Allen *et al*. (2007) found a significant (P<0.001) decrease (0.8 log_{10} cfu) in the number of *Campylobacters* on chicken carcasses from just before to after chilling. Rosenquist *et al*. (2006) reported that air and water chilling of poultry carcasses in two different plants caused significant reductions of 0.83 and 0.97 log_{10} cfu/g in thermotorelant *Campylobacters*, respectively. In one plant an additional reduction of 1.38 log_{10} cfu/g was observed for packed frozen chickens (Rosenquist *et al*., 2006). The mean values for total aerobic counts, total coliform counts and generic *Escherichia coli* counts were 1.17, 0.03, and 0.01 log_{10}, cfu/cm^2, respectively, after pasteurization and remained the same or were reduced to 0.89, 0.02, and 0.01 log_{10} cfu/cm^2 after chilling (Corantin *et al*., 2005). Huezo *et al.* (2007) investigated the effects of air and immersing chilling on *Campylobacter*, *Salmonella*, *Escherichia coli* and coliforms recovered from broiler chicken carcasses and demonstrated that a 90% reduction in the concentrations of *Campylobacter*, *Escherichia coli* and coliforms could be obtained with chilling. A review by Loretz *et al*. (2010) reported that freezing has been used to obtain reductions of 1.3 to 2.2 cfu/g of *Campylobacters* on meat carcasses majority of which are from naturally contaminated poultry carcasses. Boysen and Rosenquist (2009) evaluated various physical decontamination methods to control *Campylobacter* in broiler carcasses and reported that freezing was more effective than air chilling, or steam-ultrasound.

5.5 Packaging

Packaging methods make use of gases surrounding meats and meat products to control bacterial foodborne hazards. Oxygen, carbon dioxide and nitrogen gases are the main gases modified for the control of bacterial foodborne hazards. Different packaging methods including modified atmosphere packaging, vacuum packaging as well as aerobic packaging have been used to control specific bacterial foodborne hazards. Boysenet *et al.* (2007) found that *Campylobacter jejuni* died significantly in oxygen containing gas mixture (70/30% O2/$CO_{2)}$ compared to nitrogen containing gas mixture (70/30% N2/CO_2). A reduction of 2.0-2.6 log_{10} cfu/g happened after 8 days in oxygen containing gas mixture, while no reduction occurred for the nitrogen containing gas mixture. Rajkovic *et al.* (2010) evaluated the ability of *Campylobacter jejuni* to survive under high oxygen and carbon dioxide atmosphere after decontamination with lactic acid/sodium lactate buffer and reported a reduction of approximately 1.2 log cfu/g of *Campylobacter jejuni* under modified atmosphere package of 80% O_2/20% N_2, approximately 1.5 log cfu/g reduction under storage of 80% O_2/20% N_2 and no reduction under storage of 80% CO_2/20% N_2. They concluded that buffered lactic acid and high oxygen modified atmosphere packaged has the potential of reducing *Campylobacter jejuni* on both inoculated and naturally contaminated sources. George *et al.* (1998) found that the heat resistance of *Escherichia coli* O157:H7, *Salmonella* Enteritidis and *Listeria monocytogenes* cells were eightfold lower when they were grown, heated and recovered aerobically rather than anaerobically. Therefore, packaging using reduced oxygen concentration (<2% O_2) as found in packaging under an anaerobic atmosphere or vacuum package might increase the risk of *Escherichia coli* O157:H7, *Salmonella* Enteritidis and *Listeria monocytogenes* surviving heat treatment and consequently their control (George *et al.*, 1998).

Table 5 lists a number of prevention and control measures/methods and their probable action against bacterial foodborne hazards.

From Table 5, all the preventive measures except HACCP principles would only prevent and reduce contamination by bacterial foodborne hazards. Preservation and packaging methods would usually prevent and control bacterial foodborne hazards at the same time. Preservation and packaging methods mostly works on specific bacterial foodborne hazards. Thermal and other treatments would normally control bacterial foodborne hazards by reducing their numbers or by killing them.

6. Challenges

Human life style is dynamic. There is the tendency towards eating out or eating ready to eat foods. Consumers are also becoming increasingly aware of food safety. Public health, governmental or non governmental institutions are available to enforce food safety. There is also much international travelling and food trade. This means meat producers and meat processing industries have to put in place stringent measures to meet the demands of consumers, governmental, non governmental and all stakeholders to produce meats and meat products devoid of bacterial foodborne hazards as much as possible. Bacterial foodborne hazards are capable of undergoing certain physiological and biological processes to resist prevention and control measures. Examples include having spores that can easily be spread by air, developing spores that are more heat resistant, formation of biofilms, formation of antibiotic inhibitors and mutations. Meats are also rich in protein and contains high amount of water that favours the growth of bacterial foodborne hazards. Climatic changes can sometimes favor the growth and survival of bacterial foodborne hazards and may enable bacteria to develop resistant to prevention and control measures or methods. For instance, under better climatic conditions bacteria growth is high and much effort would be required to control them. Under harsh climatic conditions, bacterial hazards can also develop adaptions that would enable them to resist control when necessary. The existence of variety of animal species require the development, modification and/or adjustment of existing prevention and control measures to meet the requirement for different species of animals. Furthermore, some existing control measures -

Table 5: Prevention and control measures/methods and their probable action against bacterial foodborne hazards

Method/measures	Prevention	Control	Killing	Reduction of numbers
Good agricultural practices	x			x
Good manufacturing practices	x			x
HACCP	x	x	x	x
Education	x			x
Good hygienic practices	x			x
Personal Hygiene	x			x
Biosecurity	x			x
Sanitization	x	x	x	x
Thermal treatment				
Scalding		x	x	x
Singeing		x	x	x
Hot water washing		x	x	x
Steaming		x	x	x
Cooking		x	x	x
Roasting		x	x	x
Smoking		x	x	x
Preservation				
Drying	x	x	x	x
Salting	x	x	x	x
Curing	x	x	x	x
Chilling	x	x	x	x
Freezing	x	x	x	x
Fermentation	x	x	x	x
Packaging				
Modified atmosphere	x	x	x	x
Vacuum	x	x	x	x
Aerobic	x	x	x	x
Others				
Lactic acid treatment		x	x	x
Acetic acid treatment		x	x	x
Trisodium phosphate		x	x	x
Chlorine treatment		x	x	x
High pressure processing		x	x	x

and methods have meat quality defect problems (hot water treatment) or appear to face consumers' acceptability (radiation treatment). Finally, there can be challenges with practically transforming laboratory experiments with greater success in the control of bacterial foodborne hazards into real situation or commercialization.

7. Future Trends

Future developments would emphasize more on prevention measures instead of control methods. Prevention measures like the adherence to good agricultural practices, biosecurity, good manufacturing practices, good hygienic practices, personal hygiene, and hazard analysis and critical control point principles would continue to be given much priority. Control methods would have to take into consideration changes in climatic conditions and how that will reduce the effectiveness of control methods and influence the ability of bacterial foodborne hazards to become more resistant to adverse conditions. The combination of two or more different control methods (e.g. steam+radiation+vacuum package) rather than a single method would increase in application.

8. Conclusion

Meats and meat products are rich media for the growth of bacterial foodborne hazards and their consumption contribute to human foodborne infections. Bacterial foodborne hazards can also grow and adapt to different and harsh environmental conditions to resist prevention and control measures or methods. Nonetheless, the prevention and control of bacterial foodborne hazards in meats and meat products is necessary to reduce human foodborne infections. Prevention measures include good agricultural practices, good manufacturing practices HACCP and education, while control methods include thermal treatments, the use of preservatives, packaging methods and organic treatments. Preventive measures will continue to play more important role in the avoidance of contamination by bacterial foodborne hazards and consequently human foodborne infections. Control methods would also continue to explore the combination of two or more different methods.

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